



Energy, Mines and
Resources Canada

Energie, Mines et
Ressources Canada

CANMET

Canada Centre
for Mineral
and Energy
Technology

Centre canadien
de la technologie
des minéraux
et de l'énergie

CALIBRATION OF THE PYLON AB-5/EL AND AB-5/PRD SYSTEMS, TWO CONTINUOUS RADON GAS MONITORS

J. BIGU

ELLIOT LAKE LABORATORY

MARCH 1986



27pp

CALIBRATION OF THE PYLON AB-5/EL AND AB-5/PRD SYSTEMS,
TWO CONTINUOUS RADON GAS MONITORS

by

J. Bigu*

ABSTRACT

A technical evaluation and calibration of two radon gas continuous monitoring systems has been conducted in a large Radon/Thoron Test Facility (RTTF). The monitors have been developed and manufactured by Pylon Electronics Development (Ottawa, Canada). Tests were conducted under the following environmental conditions: Low relative humidity and low aerosol concentration; high relative humidity and low aerosol concentration; and high relative humidity and high aerosol concentration. The radon gas concentration in the RTTF was maintained within $\pm 10\%$ over the duration of the tests. The performance of the two systems, one based on passive diffusion through a porous material and the other based on electrostatic deposition, was rather poor and large differences were observed between the standard methods used in the RTTF to measure the radon gas concentration, and the two systems. Some suggestions and recommendations are made to improve the performance of the monitors.

*Research Scientist and Radiation/Respirable Dust/Ventilation Project Leader, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario.

ÉTALONNAGE DES SYSTÈMES PYLON AB-5/EL ET AB-5/PRD,
DEUX MONITEURS EN CONTINU DE RADON

par

J. Bigu*

RÉSUMÉ

L'évaluation et l'étalonnage techniques de deux moniteurs en continu de radon ont été effectués dans une large enceinte servant à l'expérimentation sur le radon (thoron). Les moniteurs ont été mis au point et manufacturés par Pylon Electronics Development (Ottawa, Canada). Les essais ont été menés dans les conditions environnementales suivantes: humidité relative basse et faible concentration d'aérosols, humidité relative élevée et faible concentration d'aérosols et enfin, humidité relative élevée et concentration élevée d'aérosols. La concentration de radon dans l'enceinte a été maintenue dans l'intervalle de $\pm 10\%$ pendant toute la durée des essais. Le rendement obtenu des deux systèmes, dont l'un est basé sur la diffusion passive à travers un matériau poreux et l'autre sur le dépôt électrostatique, a été assez faible. En outre, de grandes différences ont été observées entre les méthodes habituelles, utilisées dans l'enceinte lors des essais effectués pour mesurer la concentration de radon, et les deux systèmes. Le présent rapport contient aussi quelques suggestions et recommandations visant à améliorer le rendement des moniteurs.

*Chercheur scientifique et chef d'un projet de recherches sur les rayonnements, les poussières respirables et la ventilation, Laboratoire d'Elliot Lake, CANMET, Énergie, Mines et Ressources Canada, Elliot Lake (Ontario).

CONTENTS

	<u>Page</u>
ABSTRACT	i
RESUME	ii
INTRODUCTION	1
DESCRIPTION OF THE AB-5/EL AND AB-5/PRD SYSTEMS	2
EXPERIMENTAL PROCEDURE	4
EXPERIMENTAL RESULTS AND DISCUSSION	7
REMARKS AND RECOMMENDATIONS	10
ACKNOWLEDGEMENTS	11
REFERENCES	11

TABLES

<u>No.</u>		
1.	Data pertaining to the calibration of the AB-5 #202 and EL #103 system in the RTTF	13
2.	Data pertaining to the calibration of the AB-5 #208 and EL #107 system in the RTTF	14
3.	Data pertaining to the calibration of the AB-5 #208 and EL #107 system in the RTTF	15
4.	Data pertaining to the AB-5 #205 and PRD #111 system in the RTTF	16
5.	Data pertaining to the calibration of the AB-5 #202 and EL #103 system in the RTTF	17

FIGURES

1.	Radon gas concentration versus time for the AB-5 (#202)/EL (#103) system	18
2.	Radon gas conceneration versus time for the AB-5 (#202)/EL (#103) system	19
3.	Radon gas concentration versus time for the AB-5 (#208)/EL (#107) system	20
4.	Radon gas concentration versus time for the AB-5 (#208)/EL (#107) system	21
5.	Radon gas concentration versus time for the AB-5 (#205/PRD (#111) system	22

INTRODUCTION

Radiation environments pose potential hazards to human health, hence, the need for adequate monitoring of radiation levels. Radiation monitoring is also important for engineering purposes such as the maintenance of reliable air quality control in working areas.

Monitoring of the short-lived decay products of radon, i.e., radon daughters, in uranium mines for dose exposure purposes is mandatory in Canada and other countries. Radon daughter levels in dwellings of residential areas must be on average below 0.02 WL, where WL stands for Working Level.

Radon and radon daughter levels can be measured by means of a variety of instruments of the passive and active type, using techniques which range from grab-sampling to time-integrating and continuous monitoring, employing a variety of radioactivity counting methods.

The degree of accuracy with which the radiation level can be measured depends on the type of instrument, and technique and method used. If the technique and method used are standardized, the ultimate accuracy of radioactivity measurements depends directly on the type of instrument used. Hence, calibration of radiation instrumentation in well-known, i.e., standard, radioactivity atmospheres is very important. Calibration of radon and radon daughter instrumentation is commonly carried out in special installations known as radon chambers.

This report presents data on a technical evaluation and calibration of two commercially available radon gas monitors developed by Pylon Electronic Development (Ottawa, Canada). The monitors consist of a multipurpose scaler Model AB-5 and a radon gas detector, Model EL or Model PRD. For simplicity, the monitors will be referred to hereafter as the AB-5/EL system, or the AB-5/PRD system. In their usual way of operation, the monitors have been

designed to operate on a continuous basis.

The evaluation of the monitors was conducted in a large Radon/Thoron Test Facility (RTTF). The calibration of the monitors was requested by the Atomic Energy of Canada Ltd. (AECL) for a monitoring and remedial action program in some Elliot Lake dwellings.

DESCRIPTION OF THE AB-5/EL AND AB-5/PRD SYSTEMS

The scaler Model AB-5 is a microprocessor-controlled instrument which consists of a photomultiplier tube, a scaler provided with a digital read-out and a non-volatile memory, and a variable flow rate sampling pump that can operate between 0.1 and 4.0 L/min. according to the manufacturers specifications. The photomultiplier tube is located at the end of a re-entrant cavity where some sampling heads, e.g., the PRD, are located.

The scaler Model AB-5 was used in conjunction with two different radon gas detectors, or sampling heads, namely:

- a) A passive radon detector (PRD) consisting of a chamber or sensitive volume which permits the passage of radon gas through a permeable membrane while at the same time removing the radon daughters. Radon gas flows through the permeable material by passive diffusion. The sensitive volume of the PRD is coated with a chemical scintillation compound, ZnS(Ag), for α -particle detection. The PRD is designed to fit snugly into the photomultiplier tube of the AB-5 for α -particle counting, in conjunction with its associated electronic circuitry and the scaler;
- b) An electrostatic radon gas detector (EL) consisting of a 5 L cylindrically shaped chamber with a re-entrant photomultiplier tube coupled to a ZnS(Ag) screen. The screen is covered with aluminized mylar at a negative electrical potential relative to the walls of the chamber.

Because the performance and sensitivity of devices operating on

electrostatic principles are air moisture content dependent, it is necessary to ensure that the sample passing through the EL detector has a constant air moisture content. This is best accomplished by letting the sample through a desiccator column prior to entering the sensitive volume of the EL. The principle of operation of this device is simple. Radon daughters formed during the transit of radon gas through the sensitive volume of the EL are attracted by electrostatic means to the ZnS(Ag) screen. This is so because recently formed, i.e., unattached, radon daughters are found in a positively charged state, and hence can be directed or collected on a negatively charged electrode.

The AB-5/EL and AB-5/PRD monitors are designed to operate continuously, although they can also operate intermittently. The monitors are programmable, i.e., the sampling time and frequency of the counting periods can be chosen at will. Data can be stored in the memory unit and retrieved at a later time, or they can be printed out by means of an external printer. If the data do not need to be displayed in real time, i.e., by the digital read out unit, and/or the printer, but are to be retrieved at a later time, an interface unit Model CI-55 is required.

The monitors provide α -particle count accumulated during the pre-programmed sampling time. Conversion of α -particle count to radon gas concentration, [^{222}Rn], is done with the help of specially developed computer software which uses a conversion factor to convert α -particle count rate, in counts per minute (cpm), into radon gas concentration, in pCi/L.

Three AB-5 scalers were used, each operating in conjunction with a different EL or PRD detector head. The following AB-5/EL or AB-5/PRD sets were used: AB-5 #202 with EL #103; AB-5 #208 with EL #107; and AB-5 #205 with PRD #111.

The operating characteristics (settings and other variables) for the

AB-5/EL system were as follows:

High voltage setting*	: 5.5 or 4.8
Discriminator setting*	: 5.0 or 5.5
Sampling flow rate	: 1 L/min
Sampling time	: 60 min
Conversion factor	: 5.5 cpm/pCiL ⁻¹

* The AB-5 #202 with EL #103 used 5.5 and 5.0 as high voltage (H.V.) and discriminator (D) settings, respectively, whereas AB-5 #208 with EL #107 used 4.8 and 5.5 as H.V. and D settings, respectively.

The operating characteristics for the AB-5/PRD system were as follows:

High voltage setting	: 5.5
Discriminator setting	: 5.0
Sampling flow rate	: 0 L/min (passive means)
Sampling time	: 60 min
Conversion factor	: 1.1 cpm/pCiL ⁻¹

EXPERIMENTAL PROCEDURE

Testing and calibration of the monitors was conducted in a large (26 m³) Radon/Thoron Test Facility (RTTF) (1). The monitors were tested under laboratory-controlled environmental conditions of temperature, relative humidity, aerosol concentration and radon concentration.

Tests were conducted during March 1985, and during the period June/July, 1985. Tests conducted in March are not included here because of some instrument malfunction, some incorrect information given to the Elliot Lake Laboratory regarding instrument settings, uncertainty with regards to pump flow rate, as recommended by the manufacturers, difficulties in maintaining a given flow rate, and other problems.

The particular environmental conditions for each test are given in the

section on experimental results. In broad terms, however, the range of some of the environmental conditions in the RTTF were as follows. Temperature varied between 22°C and 29°C with a maximum temperature variation during a 24-h period of <4°C. The average temperature during the test was about 24.6°C. The relative humidity varied between 32% and 86%. The maximum variation in relative humidity during a 24-h period was <3%. Experiments were preferentially conducted at low relative humidities (30-45%), and at high relative humidities (76-86%).

Aerosol concentration was varied from less than $1.0 \times 10^3 \text{ cm}^{-3}$ to $8.0 \times 10^4 \text{ cm}^{-3}$. The aerosol concentration ranges of interest were: low ($\leq 1.0 \times 10^3 \text{ cm}^{-3}$), intermediate ($1.0 \times 10^3 - 3.0 \times 10^3 \text{ cm}^{-3}$), and high ($1.0 \times 10^4 - 8.0 \times 10^4 \text{ cm}^{-3}$).

Two major operating conditions were selected, namely: low aerosol concentration ($\leq 1.0 \times 10^3 \text{ cm}^{-3}$)/low relative humidity ($\leq 40\%$), and high aerosol concentration ($> 6.0 \times 10^4 \text{ cm}^{-3}$)/high relative humidity ($\sim 85\%$). An aqueous solution of NaCl (1 g/L) was used to produce the aerosol cloud. Aerosols were generated using an atomizer manufactured by TSI (Minneapolis, U.S.A.) Model 3076, in conjunction with its associated air supply system, column desiccator, and electrical charge neutralizer, also manufactured by TSI.

Variable relative humidity conditions are important because the sensitivity of the AB-5/EL system is air moisture-content dependent. The use of the column desiccator was intended to eliminate this dependence. However, because the desiccant is slowly being used up, it is unavoidable that air emerging from the column desiccator, and entering the EL detector, changes its moisture content, thereby altering the sensitivity of the detector.

Experiments were conducted within a narrow range of radon gas concentrations, [^{222}Rn], i.e., 40-50 pCi/L. The variation in radon gas concentration over a period of one week was about $\pm 10\%$.

Radon and radon daughter atmospheres were produced by injecting radon gas, ^{222}Rn , into the RTTF by means of radon gas flow-through sources Model Rn-1025 manufactured by Pylon Electronic Development (Ottawa, Canada). Radon gas and aerosol were injected into the RTTF through injection ports located opposite to the air exhaust system.

Radon gas in the RTTF was continuously monitored by means of two radon gas monitoring systems, namely the Radon Gas Monitor Model RGM-2, manufactured by Eberline (U.S.A.), and an in-house developed radon gas monitoring system operating on a similar principle to that of the RGM-2. The in-house developed system, and the RGM-2, provided radon gas concentration measurements every 20 min. and 60 min. respectively. In addition, radon gas concentrations were periodically measured by grab-sampling, using the scintillation cell method, and by the two-filter method (2.3).

Radon gas measurements were conducted at least at two different locations simultaneously in an area where the radiation instruments to be calibrated were located. Data from different locations were taken and an average value was calculated in each case.

Air temperature, relative humidity and barometric pressure were measured using a meteorological package manufactured by alpha-NUCLEAR (Toronto, Canada), consisting of a data logger Model 601 in conjunction with air temperature, dew point and barometric pressure probes Models 602, DS-001 and 604, respectively. Aerosol concentration was measured by drawing air samples continuously, in a recirculating mode, through two condensation nuclei counters, namely, Model Rich 200, manufactured by Environment One (U.S.A.), and Model 3020, manufactured by TSI (U.S.A.).

The monitors to be tested were placed in a large three-shelf metal mesh structure so designed as to produce minimum disturbance to the air flow in the RTTF. All monitors were placed on the same shelf. Care was taken to minimize

mutual monitor interference, or disturbance of air patterns by the monitors.

The radon gas concentration measured by the AB-5/PRD and AB-5/EL monitors was compared with [^{222}Rn] measured using the Radon Gas Monitor RGM-2, and the in-house developed, and calibrated, continuous system consisting of a Pylon RM-1003 scaler/photomultiplier tube system, a 100 cm^3 scintillation (ZnS(Ag)) cell and sampling pump and a Rockwell AIM-65 microcomputer to operate the system automatically. Calibration of the RM-1003/AIM-65 monitor was conducted according to the method developed by Thomas and Countess (4-7). In addition, grab-sampling measurements were carried out using the scintillation cell and two filter methods (2,3). In general, the values for the radon gas concentration measured by grab-sampling were between that corresponding to measurements using the RM-1003 (higher), and RGM-2 (lower) systems. Hence, the calibration of the AB-5/EL and AB-5/PRD systems was done taking the mean value corresponding to the above monitoring systems, i.e., [^{222}Rn] on Tables 1 to 5.

The radon gas concentrations measured by the AB-5/PRD, the AB-5/EL, and by the RGM-2, the RM 1003/AIM-65 and by grab-sampling were plotted, versus time, on the same graph for direct comparison purposes. Daily average values were obtained in all cases, for several days of experimentation during which environmental conditions were changed, and the ratio between the above monitors and the reference instrumentation was calculated for calibration purposes.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results obtained during the tests of the AB-5/EL and AB-5/PRD systems in the RTTF have been summarized in Tables 1 to 5, and Figures 1 to 5. The tables show the following data: radon gas concentration obtained with the AB-5, the in-house developed radon gas continuous monitoring

system, labelled RM-1003, and the Eberline RGM-2 radon gas continuous monitoring system. Also shown in the tables are the ratios AB-5/RM-1003 and AB-5/RGM-2, i.e., concentration ratio as obtained by the AB-5 and the RM-1003 and the RGM-2, respectively. The tables also show the temperature (T), the relative humidity (RH), the aerosol concentration (N), the disequilibrium ratios (DR), and the Working Level, as determined by the Thomas-Tsivoglou method, i.e., WL_T , measured in the RTTF.

The radon daughter disequilibrium ratios (DR) are defined by the ratios $[^{214}\text{Pb}]/[^{218}\text{Po}]$ and $[^{214}\text{Bi}]/[^{218}\text{Po}]$. The third ratio, shown as the first figure, is, by definition, unity, i.e., $[^{218}\text{Po}]/[^{218}\text{Po}]$. It should be noted that in the above ratios, the square brackets denote activity concentration. The horizontal bars on $[^{222}\text{Rn}]$ are used to indicate average values over a 24-h period. The two values for T, RH, N, DR and WL_T , shown in the tables indicate the minimum (top) and maximum (bottom) values measured during an 8-h/day period during which grab-sampling data pertaining to the above variables were taken.

The performance of the AB-5 (#202)/EL (#103) system at low relative humidity and low aerosol concentration is shown in Table 1 and Figure 1 (lower curves). Tables 5 and Figure 1 (upper curve), and Figure 2 show the response of the same system at high relative humidity and high aerosol concentration (except for July 20 and 21, during which the aerosol concentration was low). Under low aerosol concentration and low relative humidity, the above system underestimated the radon gas concentration by a factor greater than 2. At high relative humidity and high aerosol concentration, however, the system performed reasonably well, i.e., overestimated the radon gas concentration by about 15%. No satisfactory explanation can be found for the response of the instrument at low relative humidity and low aerosol concentration, except instrument malfunction. It should be noted that the high voltage and

discriminator settings for this system were slightly different from those corresponding to the AB-5 (#208)/EL (#107) (see Tables 1 and 5, and Figures 2 and 3).

The response of the AB-5 (#208)/EL (#107) system at low aerosol concentration and low relative humidity is shown in Table 2 (June 23-28) and Figures 3 and 4 (lower curves) and Table 3 (July 11-16) and Figure 3 (upper curves; July 11-14 data not plotted). The data presented show that the above system overestimated the radon gas concentration by about 21% to 36%. Table 3 (July 17-19) and Figures 3 and 4 (upper curves) show the behaviour of the system under conditions of high relative humidity and high aerosol concentration. The radon gas concentration was substantially underestimated. Furthermore, the performance of the system seems to deteriorate with time. A plausible explanation for this is the development of breakthrough paths in the desiccator column, thereby allowing gas to reach the EL detector before the water vapour has effectively been removed. This would cause a sensitivity drop, as the latter varies inversely with relative humidity.

Table 4 and Figure 5 show data pertaining to the AB-5 (#205)/PRD (#111) system under high relative humidity and either low aerosol concentration (upper curves), or high aerosol concentration (lower curves). In both cases, the above system overestimated the radon gas concentration by about 46%, on average, a figure which increased with time.

In broad terms, the performance of the AB-5/EL and AB-5/PRD systems can be considered poor, and somewhat unreliable under our experimental conditions. We cannot offer any satisfactory explanation to account for the data collected, except the suggestion that the counting sensitivity values given by Pylon may vary substantially for different EL and PRD detectors. The values given from the manufacturer were identical for similar systems and so were the high voltage and discriminator settings.

REMARKS AND RECOMMENDATIONS

There are some concerns regarding the design and operation of the AB-5 scaler, and the EL and PRD sampling heads. Some considerations are outlined below.

1. The AB-5 is not equipped with a servo-controlled sampling pump. Hence the flow rate is not maintained constant, and air flow readjustment is required frequently. Although small flow rate fluctuations are not a critical factor in the measurement of radon gas concentrations, it can, nevertheless reflect on the ultimate accuracy of the data.
2. The lack of a servo-controlled sampling pump is further complicated by the fact that the instrument is not provided with a flow-meter as an integral part of the system. Hence, no continuous air flow monitoring is possible, unless an external flow-meter is installed by the user.
3. The high voltage and discriminator settings are located on the back of the instrument. There are no adequate quality potentiometers for fine tuning and adjustment. Instrument setting is done using a screw-driver. It has been observed that the settings can change slightly during the operation of the instrument because of the vibration introduced by the pump.
4. The EL sampling head is quite sensitive to air moisture content. Hence, extreme care must be taken to ensure that air entering the system always has the same relative humidity to eliminate unwanted variations in the α -particle counting efficiency of the system.
5. At sufficiently high sampling flow-rate (≥ 1 L/min and ≤ 4 L/min), the battery charger cannot maintain the charge on the AB-5 scaler power pack for extended periods of time and the system stops operating and collecting data.
6. The AB-5/EL and AB-5/PRD systems are not ruggedized, dust proofed or

moisture proofed, and hence are unsuitable for field operations.

The performance of the systems tested here could be improved substantially by introducing some mechanical and electrical modifications into the AB-5 scaler, and taking into account other considerations as indicated above.

ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of R. Lalonde (Co-op student, Waterloo University), and S. Brown (COSEP student, Sault College of Technology and Applied Arts) in conducting some of the laboratory tests. The calibration of the instruments was requested by Atomic Energy of Canada Limited (AECL), who assigned Mr. Lalonde to this project. The author is most appreciative to B. McCallum (AECL) for his input during this project.

REFERENCES

1. Bigu, J., "A walk-in radon/thoron test facility"; Am Ind Hyg Assoc J. vol 45, No. 8, pp 525-532, 1984.
2. Thomas, J.W. and LeClare, P.C., "A study of the two filter method for radon-222"; Health Phys. vol 18, pp 113-122, 1970.
3. Mayya, Y.S. and Kotrappa, P., "Modified double filter method for the measurement of radon or thoron in air"; Ann Occup Hyg. vol 21, pp 169-176, 1978.
4. Thomas, J.W., "A system for continuous radon determination"; HASL-327, Energy Research and Development Administration, New York; July 1977.
5. Countess, R.J. and Thomas, J.W., "Radon flask monitor"; HASL-330, Energy Research and Development Administration, New York; August 1977.

6. Thomas, J.W. and Countess, R.J.. "Continuous radon monitor"; Health Phys. vol 36, p 734; 1979.
7. Grenier, M.G. and Bigu, J.. "Evaluation and calibration of a continuous radon gas monitor using the Thomas method"; Division Report MRP/MRL 83-62(TR). CANMET, Energy, Mines and Resources Canada; June 1983.

Table 1 - Data pertaining to the calibration of the AB-5 #202 and EL #103 system in the RTTF*

Date	[²²² Rn] AB-5 pCi/L	[²²² Rn] RM-1003 pCi/L	[²²² Rn] RMG-2 pCi/L	AB-5 RM-1003	AB-5 RCM-2	Average	T °C	RH %	N cm ⁻³	DR	WL _T	Remarks
June 18/85	22.0±3.4	49.1±4.8	41.9	0.45	0.52	0.49	26.0	40.0	~1.0x10 ³	1:0.15:0.05 1:0.28:0.26	39 50	
June 19	21.2±7.0	48.9±3.4	41.6	0.43	0.51	0.47	24.4 26.0	36.5 39.0	~0.4x10 ³	1:0.1:0.1 1:0.18:0.08	31 37	
June 20	14.9	46.9±6.5	41.4	0.32	0.36	0.34	25.0	36.4	0.42x10 ³ 0.65x10 ³	1:0.12:0.1 1:0.21:0.14	32 39	
June 21	17.0±2.8	49.4±9.4	42.4	0.34	0.40	0.37	25.0	34.9	0.65x10 ³ 1.0x10 ³	1:0.17:0.15 1:0.25:0.18	38 53	
						Ave: 0.42±0.07						

* H.V. setting: 5.5; Discriminator setting: 5.0.

Table 2 - Data pertaining to the calibration of the AB-5 #208 and EL #107 system in the RTTF*

Date	[²²² Rn] AB-5 pCi/L	[²²² Rn] RM-1003 pCi/L	[²²² Rn] RMG-2 pCi/L	AB-5 RM-1003	AB-5 RGM-2	Average	T °C	RH %	N cm ⁻³	DR	WL _T	Remarks
June 23/85	57.9±10.4	48.5±5.5	42.2	1.19	1.37	1.28	26.0	45.5	0.65x10 ³ 1.2x10 ³	-	-	
June 24	60.3±3.6	47.9±4.4	40.0	1.26	1.51	1.38	24.6	33.1	0.28x10 ³	1:0.08:0.07	21	
							26.0	33.4	0.38x10 ³	1:0.14:0.04	25	
June 25	60.8±3.6	47.2±5.5	40.9	1.29	1.49	1.38	24.9	32.6	0.65x10 ³	1:0.07:0.09	24	
							27.3	32.8	1.25x10 ³	1:0.17:0.02	31	
June 26	58.9±8.0	47.9±6.4	41.1	1.23	1.43	1.33	26.0	31.0	0.8x10 ³	1:0.1:0.08	29	Drierite changed
							30.1	31.5	3.0x10 ³	1:0.21:0.1	36	at 8:46
June 27	66.1±8.5	52.5±7.7	45.3	1.26	1.46	1.36	24.0	32.9	0.65x10 ³	1:0.12:0.07	32	
							27.8	33.2	1.5x10 ³	1:0.23:0.24	46	
June 28	65.0±5.7	50.0±7.7	42.4	1.30	1.53	1.42	24.8	35.5	0.65x10 ³	1:0.19:0.15	37	
							28.9	36.8	1.85x10 ³	1:0.28:0.08	56	
						Ave: 1.36±0.05						

* H.V. setting: 4.8; Discriminator setting: 5.5.

Table 3 - Data pertaining to the calibration of the AB-5 #208 and EL #107 system in the RTTF*

Date	$\left[\frac{^{222}\text{Rn}}{\text{AB-5}} \right]$ pCi/L	$\left[\frac{^{222}\text{Rn}}{\text{RN-1003}} \right]$ pCi/L	$\left[\frac{^{222}\text{Rn}}{\text{RGM-2}} \right]$ pCi/L	AB-5 RN-1003	AB-5 RGM-2	Average†	T °C	RH %	N cm ⁻³	DR	VL _T	Remarks
July 11/85	61.8±7.1	53.2±5.9	45.3	1.16	1.36	1.26	24.0 30.0	31.0 37.0	0.3×10 ³ 3.0×10 ³	1:0.08:0.07 1:0.28:0.08	21 56	
July 12	76.3±11.2	59.2±10.0	51.1	1.29	1.49	1.39	24.0 30.0	31.0 37.0	0.3×10 ³ 3.0×10 ³	1:0.08:0.07 1:0.28:0.08	21 56	
July 13	71.6±8.6	59.2±7.1	49.0	1.21	1.46	1.33	24.0 30.0	31.0 37.0	0.3×10 ³ 3.0×10 ³	1:0.08:0.07 1:0.28:0.08	21 56	
July 14	51.7±12.0	50.1±4.4	49.4	1.03	1.05	1.04	24.0 30.0	31.0 37.0	0.3×10 ³ 3.0×10 ³	1:0.08:0.07 1:0.28:0.08	21 56	
July 15	50.5±9.9	48.1±6.0	41.6	1.02	1.18	1.10	24.5 28.1	47.5 52.6	0.55×10 ³ 2.8×10 ³	1:0.16:0.15 1:0.33:0.26	38 70	
July 16	50.5±8.8	48.0±5.3	42.2	1.05	1.20	1.12	24.8 26.6	59.7 72.9	0.45×10 ³ 7.0×10 ⁴	1:0.14:0.04 1:0.7:0.47	31 268	Aerosol injected at 9:15
July 17	27.1±8.5	49.1±7.0	42.9	0.55	0.63	0.59	24.3 27.5	77.0 80.0	7.2×10 ⁴ 7.6×10 ⁴	1:0.57:0.39 1:0.77:0.66	234 334	
July 18	17.7±3.5	48.3±6.5	42.8	0.37	0.41	0.39	24.7 25.7	80.2 82.8	7.5×10 ⁴ 8.0×10 ⁴	1:0.65:0.58 1:0.90:0.73	253 333	
July 19	13.6±2.0	49.5±4.2	40.7	0.27	0.33	0.30	24.8 29.0	82.0 82.9	2.7×10 ⁴ 8.0×10 ⁴	1:0.59:0.40 1:0.95:0.71	232 358	Aerosol instability

* H.V. setting 4.8; Discriminator setting: 5.5.

† The average value for July 11-16 is 1.21±0.14.

Table 4 - Data pertaining to the calibration of the AB-5 #205 and PRD #111 system in the RTTF*

Date	$\overline{[^{222}\text{Rn}]}$ AB-5 pCi/L	$\overline{[^{222}\text{Rn}]}$ RM-1003 pCi/L	$\overline{[^{222}\text{Rn}]}$ RGM-2 pCi/L	AB-5 RM-1003	AB-5 RGM-2	Average	T °C	RH %	N cm ⁻³	DR	WLT	Remarks
July 19/85	56.3±7.1	48.3±6.4	40.7	1.17	1.38	1.27	24.8	82.0	2.7x10 ⁴	1:0.59:0.4	232	Aerosol
							29.0	82.9	8.0x10 ⁴	1:0.95:0.71	358	instability
July 20	65.2±2.5	49.5±4.2	42.9	1.32	1.52	1.42	26.0	84.0	1.8x10 ³	-	-	
July 21	67.4±3.3	50.7±4.8	43.9	1.33	1.53	1.37	24.0	84.5	2.0x10 ³	-	-	
July 22	62.2±2.8	45.5±5.0	39.9	1.37	1.56	1.46	22.1	83.0	2.1x10 ³	1:0.11:0.04	23	Aerosol inject
							23.8	83.4	7.0x10 ⁴	1:0.78:0.51	275	at 8:45
July 23	68.3±3.4	48.9±7.3	41.8	1.40	1.63	1.51	21.4	83.9	6.0x10 ⁴	1:0.56:0.43	260	
							24.7	84.3	7.0x10 ⁴	1:0.82:0.60	318	
July 24	75.7±2.8	46.1±5.5	40.2	1.64	1.88	1.76	22.6	83.9	6.8x10 ⁴	1:0.59:0.33	234	
							25.9	84.2	7.0x10 ⁴	1:0.85:0.71	288	
						Ave: 1.46						

* H.V. setting: 5.5; Discriminator setting: 5.0.

Table 5 - Data pertaining to the calibration of the AB-5 #202 and EL #103 system in the RTTF*.

Date	[²²² Rn] AB-5 pCi/L	[²²² Rn] RM-1003 pCi/L	[²²² Rn] RGM-2 pCi/L	AB-5 RM-1003	AB-5 RGM-2	Average	T °C	RH %	N cm ⁻³	DR	WL _T	Remarks
July 19/85	53.8±4.3	48.3±6.4	40.7	1.11	1.32	1.21	24.8	82.0	2.7x10 ⁴	1:0.59:0.40	232	Aerosol
							29.0	82.9	8.0x10 ⁴	1:0.95:0.71	358	instability
July 20	58.6±3.1	49.5±4.2	42.9	1.18	1.37	1.27	26.0	84.0	1.8x10 ³	-	-	
July 21	56.0±3.8	50.7±4.8	43.9	1.10	1.27	1.18	24.0	84.5	2.0x10 ³	-	-	
July 22	49.6±3.5	45.5±5.0	39.9	1.09	1.24	1.16	22.1	83.0	2.1x10 ³	1:0.11:0.04	252	Aerosol
							23.8	83.4	7.0x10 ⁴	1:0.78:0.51	275	injected at 8:45
July 23	50.1±5.8	48.9±7.3	41.8	1.02	1.19	1.10	21.4	83.9	6.0x10 ⁴	1:0.56:0.43	260	
							24.7	84.3	7.0x10 ⁴	1:0.82:0.60	318	
July 24	47.6±3.5	46.1±5.5	40.2	1.03	1.18	1.10	22.6	83.9	6.8x10 ⁴	1:0.59:0.33	234	
							25.9	84.2	7.0x10 ⁴	1:0.85:0.71	288	
July 25	48.3±3.5	47.9±5.0	40.5	1.01	1.19	1.10	24.9	85.3	6.8x10 ⁴	1:0.57:0.42	238	
							25.4	85.7	7.2x10 ⁴	1:0.79:0.65	280	
July 26	49.5±4.4	46.4±5.4	42.5	1.07	1.16	1.11	23.6	83.0	6.5x10 ⁴	1:0.63:0.51	256	
							27.1	85.3	7.0x10 ⁴	1:0.86:0.80	292	
						Ave: 1.15±0.06						

* H.V. setting 5.5; Discriminator setting: 5.0.

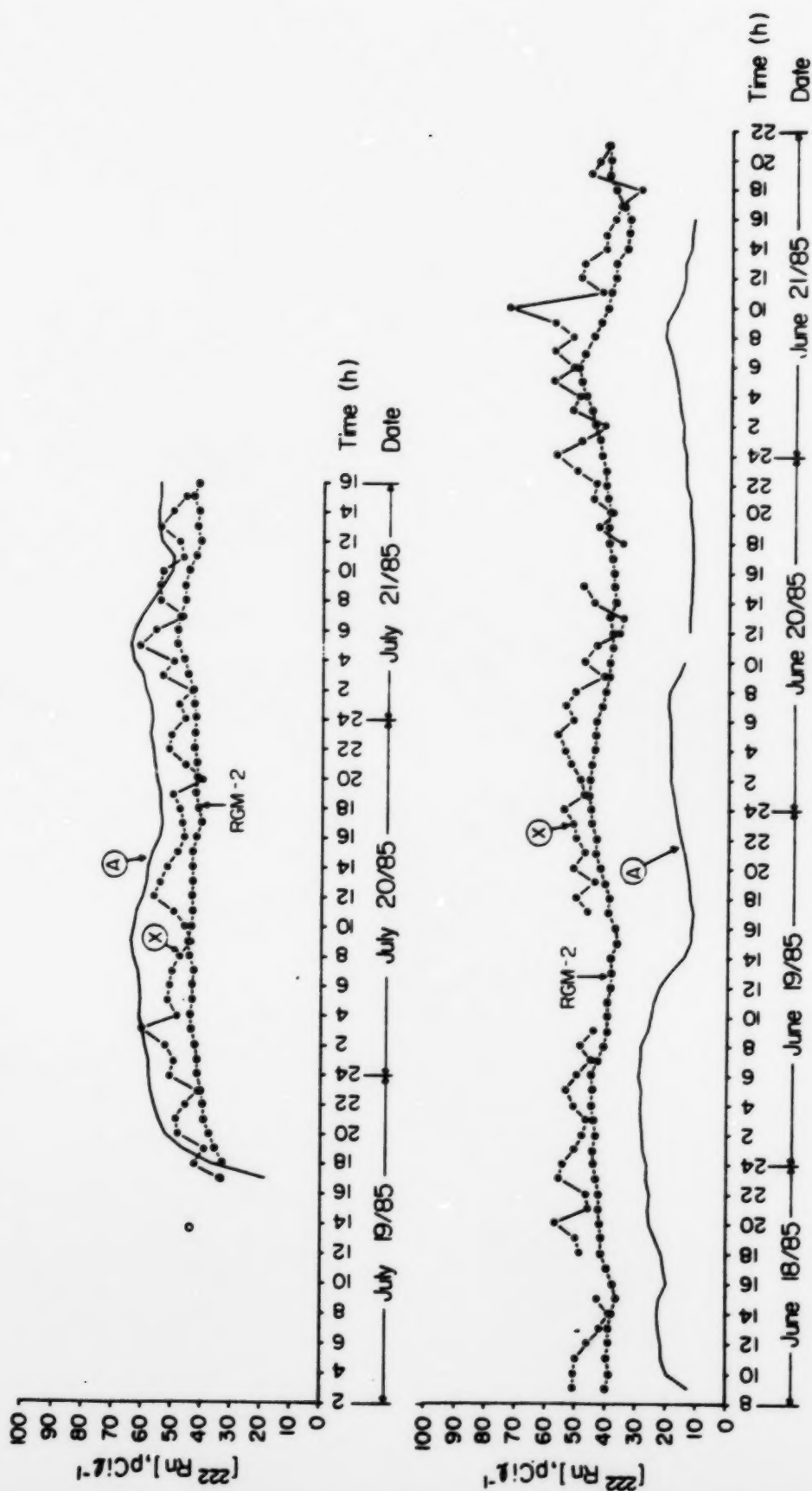


Fig. 1 - Radon gas concentration versus time for the AB-5 (#202)/EL (#103) system (curve A). Curve X shows data obtained with the in-house continuous monitoring system. Empty circles denote grab-sampling data.

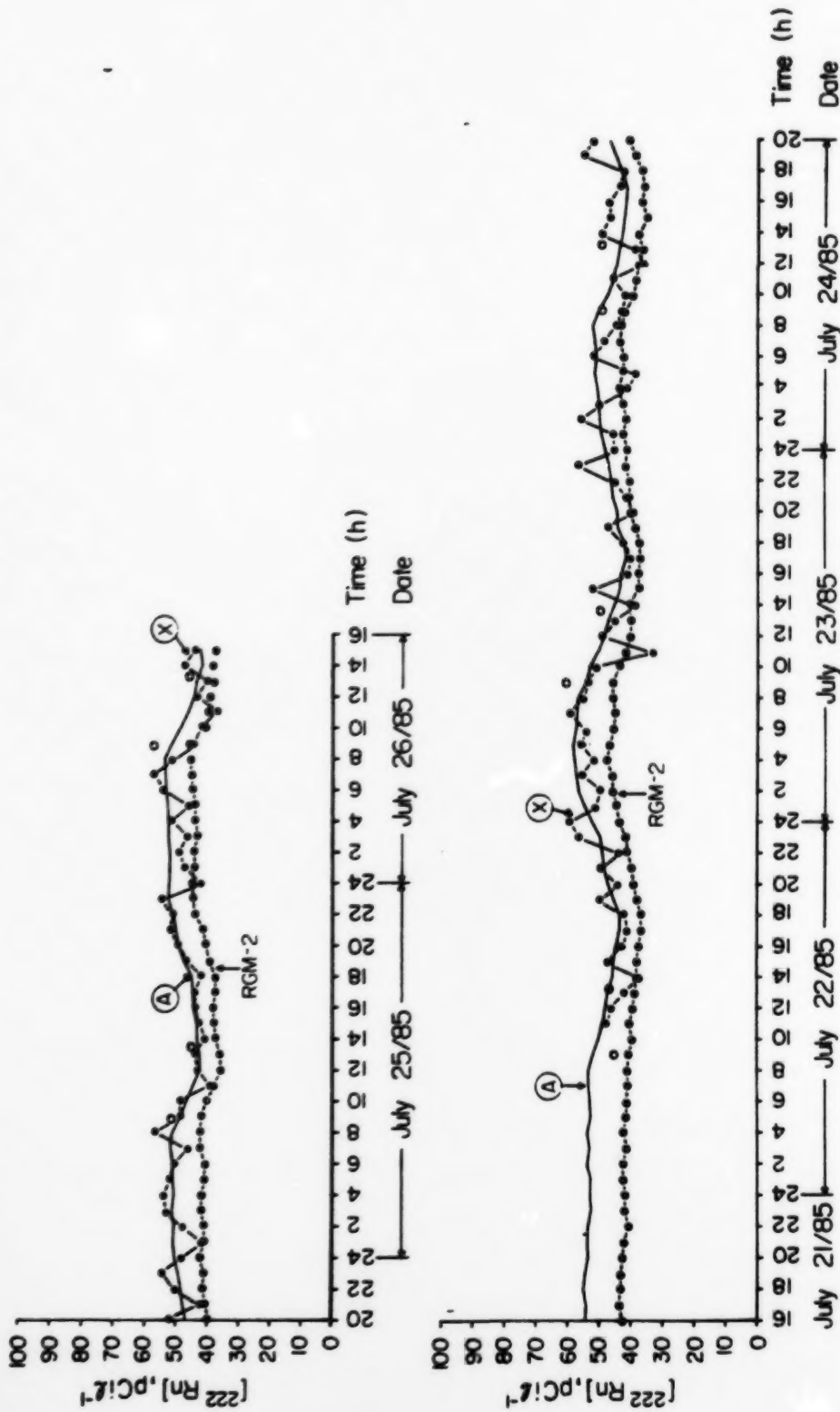


Fig. 2 - Radon gas concentration versus time for the AB-5 (#202)/EL (#103) system (curve A).
 Curve X shows data obtained with the in-house continuous monitoring system.
 Empty circles denote grab-sampling data.

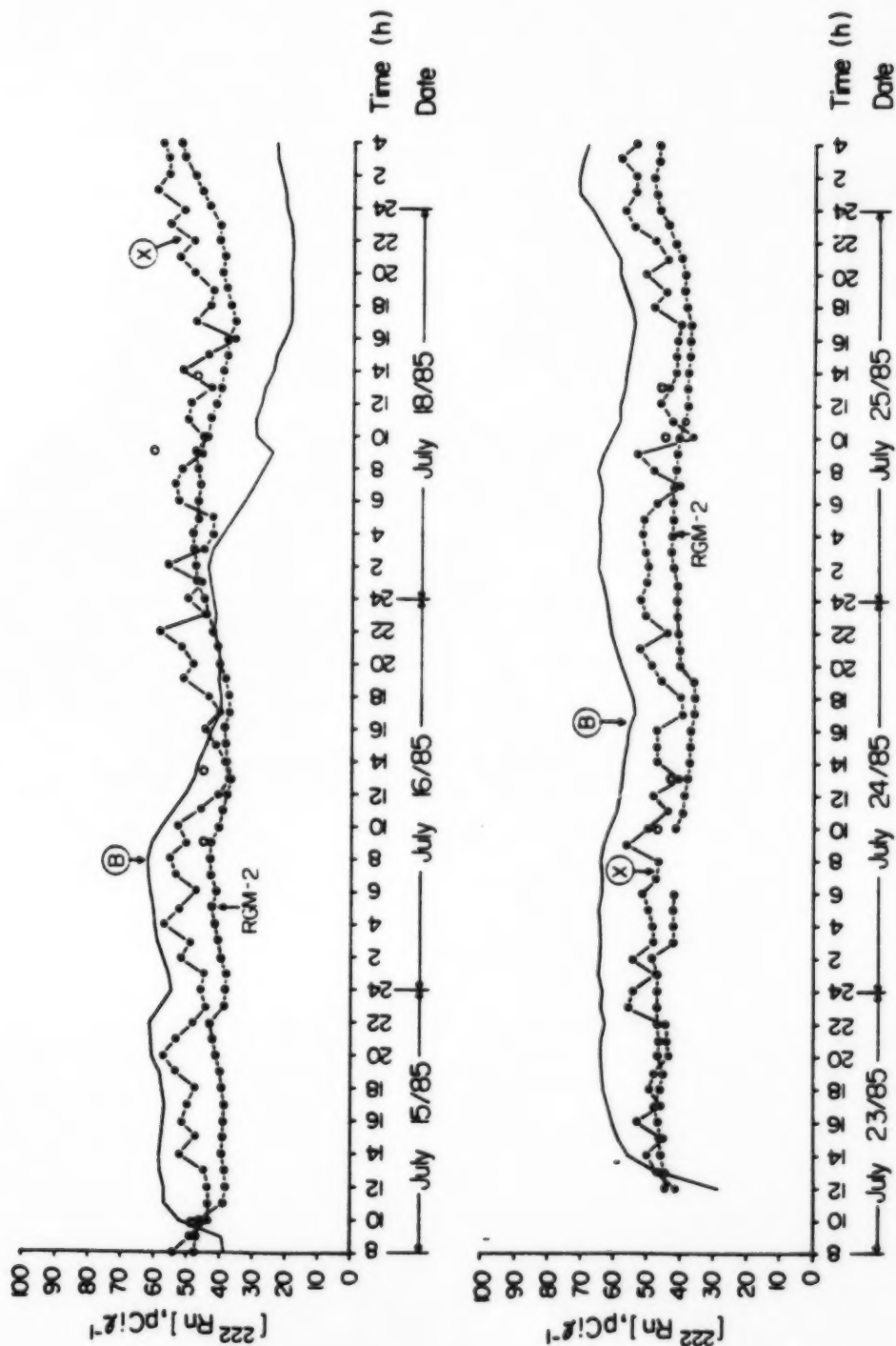


Fig. 3 - Radon gas concentration versus time for the AB-5 (#208)/EL (#107) system (curve B).

Curve X shows data obtained with the in-house continuous monitoring system.

Empty circles denote grab-sampling data.

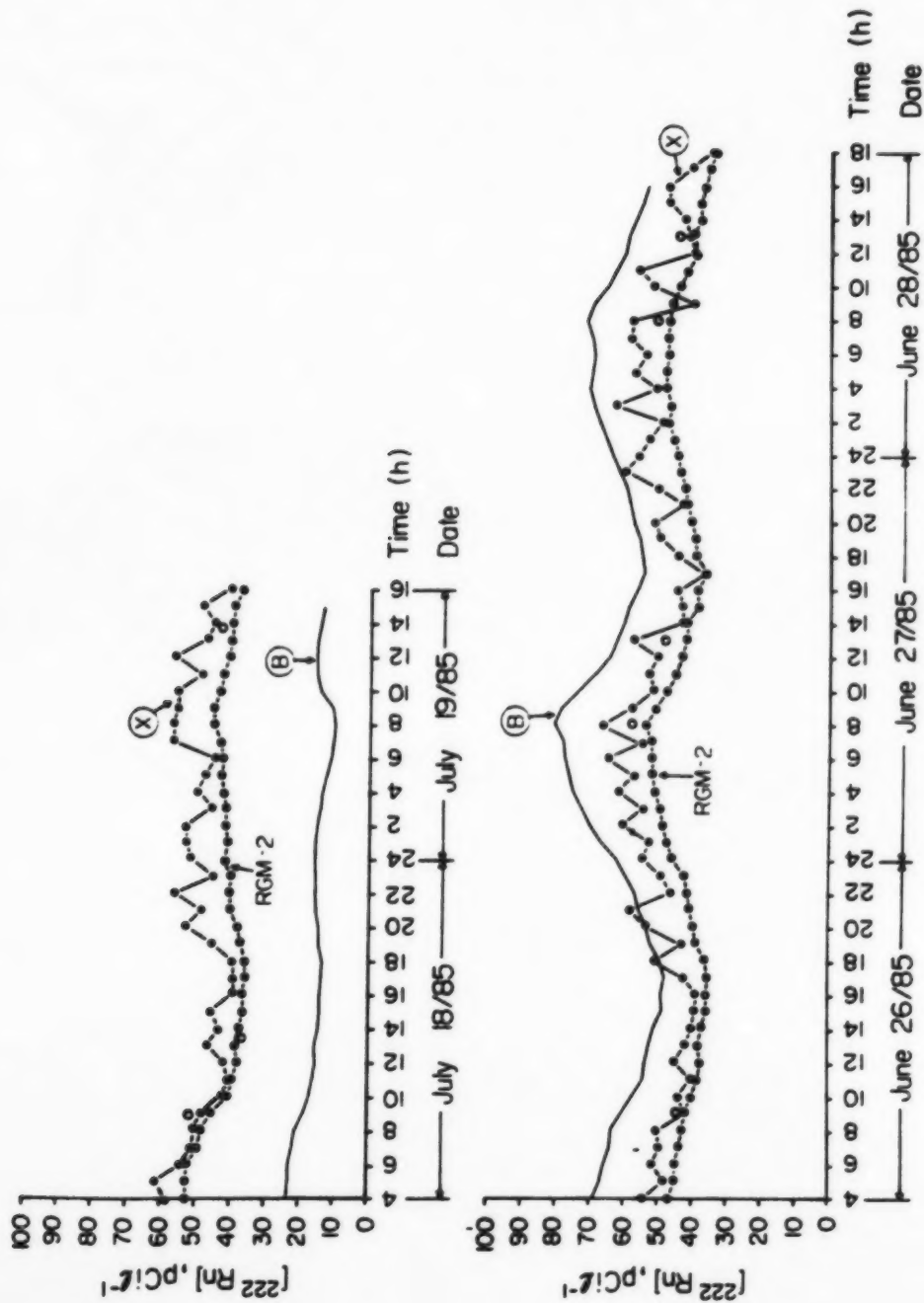


Fig. 4 - Radon gas concentration versus time for the AB-5 (#208)/EL (#107) system (curve B).
 Curve X shows data obtained with the in-house continuous monitoring system.
 Empty circles denote grab-sampling data.

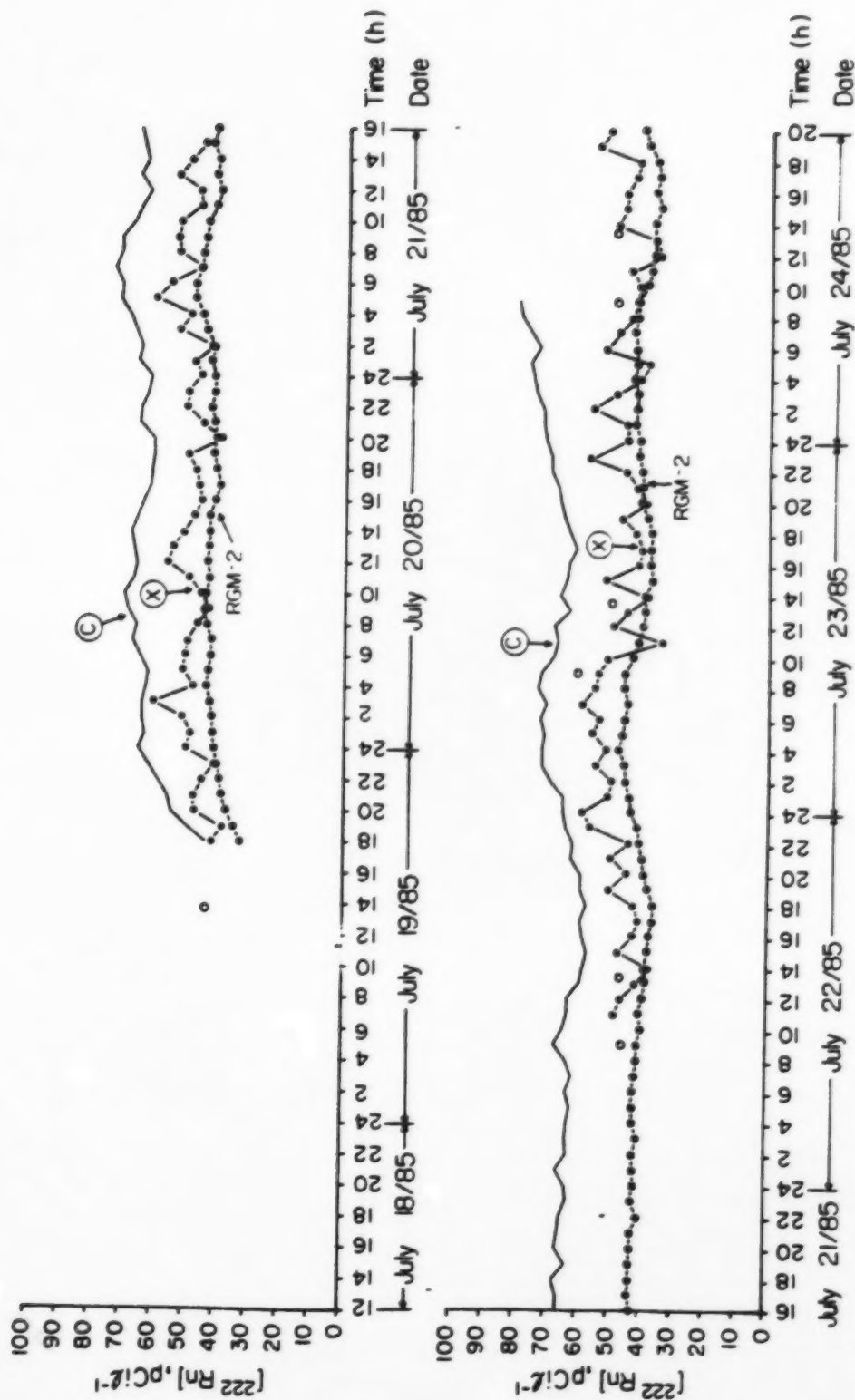


Fig. 5 - Radon gas concentration versus time for the AB-5 (#205)/PRD (#111) system (curve C).
 Curve X shows data obtained with the in-house continuous monitoring system.
 Empty circles denote grab-sampling data.